Surface morphology of $Si_{1-x}Ge_x$ relaxed alloys (x = 0.2 to 0.5)

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Introduction

Several growth methods have been used those last 10 years to obtain strain-relaxed $Si_{1-x}Ge_x$ substrates [1]. A high quality of the final constant composition layer requires the preliminary use of a SiGe graded layer to confine the misfit dislocations in its midst [2]. Obtaining a surface with a good-quality cristallinity, a low defects' density and a low "cross-hatch" surface roughness is a prerequisite for subsequent processing steps. We deal in this abstract with an optical interferometry method NT3300 (Wyko) in order to evaluate in line the surface morphology after epitaxy and other following processes. We show that Wyco is an accurate and sensitive method which can be applied to the study of relaxed SiGe substrates with miscellaneous Ge contents. Not destructive and not contaminating, it allows a fast in-line monitoring of the relaxed substrates in the same clean-room environment.

Experimental

We have used <100> oriented, 200mm SiGe relaxed layers grown on Si substrates by RP-CVD (Reduced Pressure Chemical Vapor Deposition). The structure consists of a constant composition $Si_{1-x}Ge_x$ thick layer on top of a compositionally graded $Si_{1-x}Ge_x$ layer. We have used an optical 3D profiler system (Wyco) to monitor in line the surface morphology after the epitaxy step. It is used in the PSI (Phase Shifting Interferometry) mode for the characterization of $Si_{1-x}Ge_x$ relaxed substrates with x from 0,2 up to 0,5. Two objective magnifications were used: the ×50 objective served to evaluate the Rms surface roughness and the Rmax values and to compare them with tapping mode AFM (Atomic Force Microscopy) measurements. The ×10 objective was useful to visualize the undulations (when present) on a larger scale than in AFM in order to determine the miscellaneous undulations periods.

We will only concentrate on the surface topography after epitaxy, the visualisation of cross-hatch morphology and its relationship with the Ge content.

Results-Discussion

1° Correlation NT 3300-AFM : The correlation between measurements obtained by the optical profiler and AFM is plotted figure 1 for a Ge content of 50% after a Chemical Mechanical Planarization (CMP) step. The planarization has the property of suppressing the cross-hatch pattern. This step significantly reduces the surface roughness due to the cross-hatch. The slope of the fitting line (0.96) shows a good agreement between the AFM and the PSI values. This relationship is somewhat different for surfaces where the cross-hatch is still present (Ge content from 20% up to 50%), as plotted in fig.2. The measurements taken on cross-hatched surfaces post-epitaxy are responsible for the variation of the slope of the fitting line (0.78 instead of 0.96).

2° Surface morphology after epitaxy :

The surface morphology of $Si_{1-x}Ge_x$ relaxed substrates is represented fig. 3 and 4 for x = 0.2 and 0.3. The 120 × 90µm areas displayed show an apparent cross-hatch pattern in the <110> directions. The undulations are a signature of the two perpendicular slip directions of the underlying misfit dislocations, [110] and [1-10], running across the sample. Their amplitude is accentuated for higher Ge contents (fig. 4). The technique which is used here in a clean-room environment is fast and non destructive. Whereas the scanning field size is limited in AFM by the piezoelectric crystal small excursion range, PSI allows the observation of very large imaging fields. Thus, it points out, on our relaxed SiGe substrates, the existence of a second, higher value period than the one normally observed in AFM. Indeed, two kinds of periods are measured: ~ 6 to 8 µm and 1 to 2 µm (as observed by AFM) for 20% Ge. These periods are respectively reduced to ~ 3 or 4 µm and 1 µm when the % Ge is increased to 30%. For a Ge content near 50%, the spacing between crests is smaller (≤ 3 µm), as shown in fig. 5. Similar informations are obtained in this case using tapping mode AFM (fig.6). We have plotted the evolution of the Rms roughness determined by PSI as a function of the Ge content in fig. 7. As the Ge concentration increases, the surface roughness increases significantly (factor of 3). About the same variation (factor of 3,5) is found for the corrugation height or Rmax. So, it is clear that the surface becomes rougher as the Ge content increases [3]. This roughness increase is linked to the larger amount of strain which is relaxed during the growth of the SiGe graded layer.

Conclusion

We have shown that Phase Shifting Interferometry can be used to monitor in line the surface morphology after epitaxy. Faster, not contaminating and as sensitive as AFM, it gives access to larger imaging fields. Notably, it allows to image surface undulations which are characteristic for relaxed SiGe substrates of the underlying strain field and quantify the progressive increase of their amplitude with the Ge content.

References

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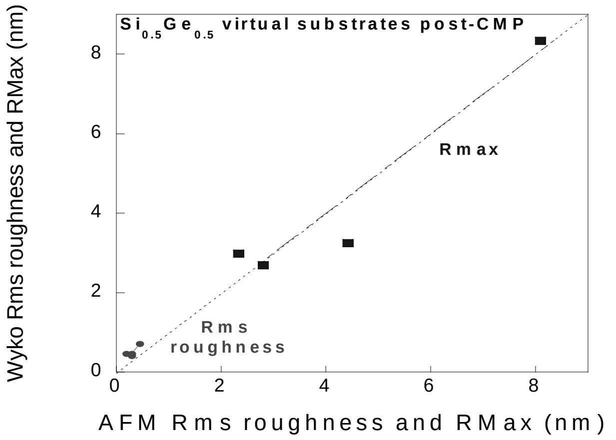

Fig. 1 Relation between the Rms and Rmax measurements obtained using Wyko with those obtained using AFM for Si $_{0.5}$ Ge $_{0.5}$ virtual substrates. (The dotted line' slope is ~ equal to 0.96).

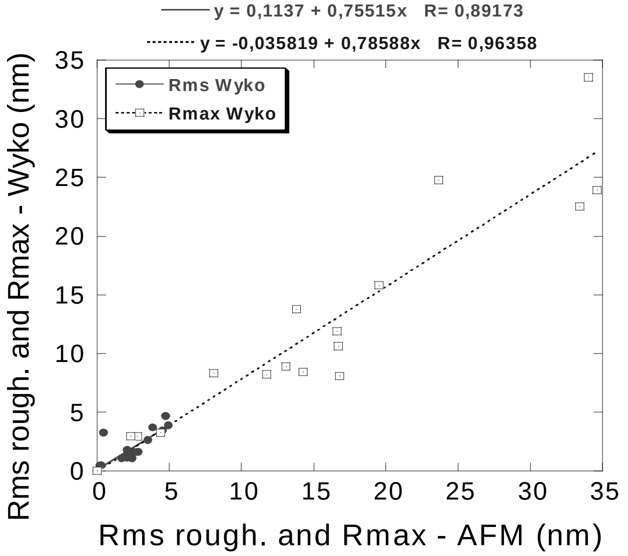

Fig. 2 Relationship between the Rms and Rmax measurements obtained using Wyco with those obtained using AFM for Si_{1-x} Ge_x (x = 0,2 to 0,5) virtual substrates. (dotted line' slope ~ 0.80).

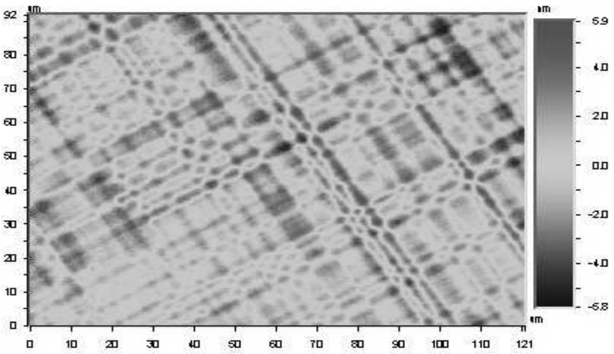

Fig. 3 Wyco image of the surface of a $Si_{0,8}$ $Ge_{0,2}$ relaxed substrate post-epitaxy. The area displayed is 120 × 90 µm (× 50 objective).

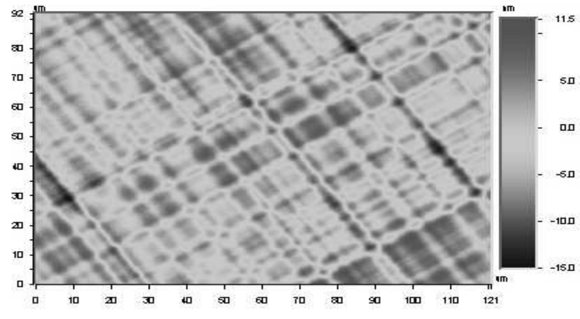

Fig. 4 Wyco image of the surface of a $Si_{0,7}Ge_{0,3}$ relaxed substrate post-epitaxy. The area displayed is 120 × 90 µm.

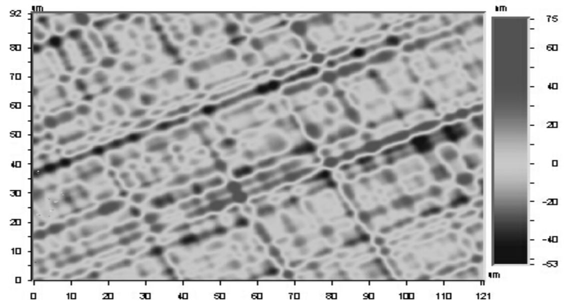

Fig. 5 Wyco image of the surface of a $Si_{0,5}Ge_{0,5}$ relaxed substrate post-epitaxy. The area displayed is 120 × 90 µm.

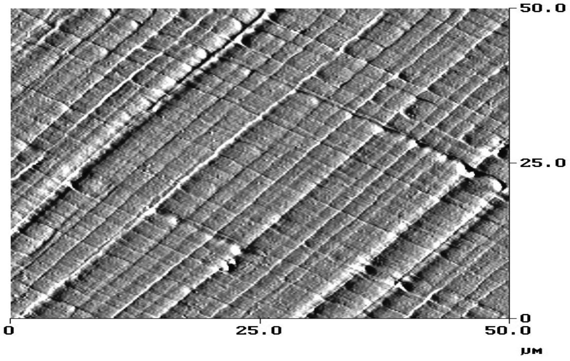

Fig. 6 50µm × 50µm AFM image of a $Si_{0,5}Ge_{0,5}$ relaxed substrate after epitaxy, to be compared with figure 5.

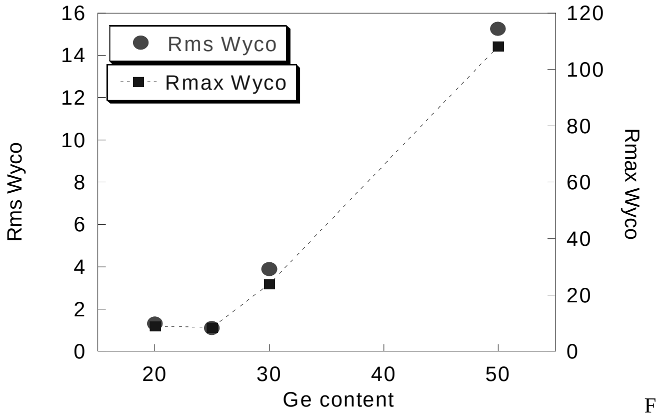

Fig 7 Rms roughness associated to the cross-hatch pattern vs final Ge concentration. These values have been determined using Wyco with a (×50) objective.